I. Project Title: Green and Yampa River Basin Sediment Monitoring Program

II. Principal Investigator:

John G. Elliott
U.S. Geological Survey
E-mail: jelliott@usgs.gov
Phone: 303-236-4882 ex 296
Fax: 303-236-4880

III. Project Summary:

The Recovery Program has identified a need to better define the requirements, appropriate methodologies, and levels of effort for a sediment monitoring program, to help define habitat requirements for endangered fishes in the Yampa, Little Snake, and Green rivers. To meet that need, an independent peer review panel was formed to review historical data, review the status of ongoing data collection efforts, identify sediment issues as they relate to recovery of endangered fishes, and develop recommendations for future sediment study to support Recovery Program efforts. The water resources of the Upper Colorado River Basin have been extensively developed for water supply, irrigation, and power generation through water storage in upstream reservoirs during spring runoff and subsequent releases during the remainder of the year. The net effect of water-resource development has been to significantly modify the predevelopment annual hydrograph as well as the timing and amount of sediment delivery from the upper Green River and the Yampa River Basins tributaries to the main-stem reaches where endangered native fish populations have been observed. This study identifies sediment source reaches in the Green River mainstem and the lower Yampa and Little Snake rivers. The study also provides sediment and streamflow data and sediment-transport relations that will be useful in assessing the potential effects of hydrograph modification by reservoir operation on sedimentation at identified razorback spawning bars in the Green River. The need for additional data collection is evaluated at each sampling site.

Sediment loads were calculated at five key areas within the watershed by using instantaneous measurements of streamflow, suspended-sediment concentration, and bedload. Sediment loads were computed at each site for two modes of transport (suspended load and bedload) as well as the total sediment load (suspended load plus bedload) where both modes were sampled. Sediment loads also were calculated for silt-and-clay, and sand-and-gravel sizes by hydrograph season. Sediment-transport curves were developed for each type of sediment load by a least-squares regression of logarithmic-transformed data.

Transport equations for suspended load and total load had coefficients of determination of at least 0.75 at all of the sampling sites except Little Snake River near Lily, Colorado where the

coefficient of determination for suspended load was 0.73 and where no bedload data were collected. Transport equations for the smaller particle sizes tended to have higher coefficients of determination than the equations for coarser sizes. Because the data had to be subdivided into at least two subsets (rising-limb, falling-limb, and occasionally, base-flow periods), the seasonal transport equations generally were based on relatively few samples. All transport equations probably could be improved by additional data collected at strategically timed periods.

IV. Study Schedule: Initial year - 1998, Final year - 2008

V. Relationship to RIPRAP:

Yampa River Action Plan: Yampa and Little Snake Rivers1.A.4.a(3)
Yampa River Operation and Management Plan

VI. Accomplishments of FY 2002 Tasks and Deliverables, Discussion of Initial Findings and Shortcomings:

The purpose of this study is to provide data and sediment-transport relations that will be useful in assessing the potential effects of hydrograph modification by reservoir operation on sedimentation at identified razorback sucker spawning bars in the Green River. Sediment data from five sites in the Yampa River Basin and the Upper Green River Basin have been collected by the USGS during an ongoing, multiyear study that began in 1998 and continued through water year (WY) 2002. These data were augmented with sediment data gathered at these sites in earlier years as part of other USGS studies and routine data collection activities.

An interpretive report based on sediment data collected through WY 2000 was prepared for publication as a U.S. Geological Survey Water-Resources Investigations Report in 2001. Since preparation of the draft, sediment data from WY 2001 and 2002 have been collected, but not analyzed. Below is a summary of the numbers of samples collected at the five sites through WY 2002:

	Through Water Year 2000		Through Water Year 2000	
Station name	Suspended sediment	Bedload sediment	Suspended sediment	Bedload sediment
Yampa River above Little Snake	14	14	25	25
Little Snake River near Lily	83	0	96	11
Yampa River at Deerlodge Park	74	49	78	53
Green R. above Gates of Lodore	23	23	33	33
Green River near Jensen	30	29	40	40

Summary and Conclusions:

(*Note figure referenced below are to the Draft Report which is not included with this annual report. The Draft Report can be obtained by calling George Smith at 303-236-5322 ex 235)*

A draft of the interpretive report was reviewed by two USGS colleague reviewers and a USGS editor. In addition, the draft report was submitted to the U.S. Fish and Wildlife Service for review by members of the Upper Colorado River Endangered Fish Recovery Program. Comments from the Recovery Program reviewers and USGS technical and editorial were incorporated into a final draft of the interpretive report. Publication of the report is being delayed temporarily pending a decision on whether to incorporate the WY 2001 and 2002 sediment data with the previously-collected data, recompute the sediment transport equations, and revise the recommendations based on those amended transport equations.

Large amounts of sediment are stored in the lower Little Snake, lower Yampa, and lower Green rivers in the form of alluvial banks, bars, and islands. These near-channel areas may be important secondary sources of sediment that periodically is entrained by the Green River and its larger tributaries. Aerial photographs made in 1988 of the channels of the Little Snake River downstream from the Lily streamflow gage, the Yampa River downstream from Cross Mountain, and the Green River from the Lodore Ranger Station to Jensen were assessed to determine the relative abundance of alluvial materials in the banks and bars. The relative abundance of subaerial alluvial deposits in the photographs varied from river to river in the watershed and from subreach to subreach along a river. Although the flood-plain width was relatively narrow and the surface area of alluvial deposits was small, the Little Snake River a few miles downstream from streamflow-gaging station 09260000 had a consistently high percentage of alluvial material along its boundaries.

The large sediment yield of the Little Snake River is reflected in the increase in relative abundance of alluvial deposits in the Yampa River immediately downstream from the Little Snake River confluence. The relative abundance of alluvial material decreases abruptly from more than 80 percent to less than 20 percent as the Yampa River flows into the steep and narrow Yampa Canyon. Alluvial deposits are relatively scarce in Yampa Canyon between River Miles 45 and 21. The canyon geomorphology in this reach is dominated by the massive limestone of the Morgan Formation; also, the river is steep and the canyon floor is narrow, providing little area suitable for significant alluvial sediment storage. The Yampa River flows through the massive Weber Sandstone downstream from River Mile 21 and, from here to the mouth, the canyon floor is wider and more conducive to sediment deposition.

The abundance of subaerial alluvial sediment in the Green River downstream from the Lodore Ranger Station is less uniform than in the Little Snake or Yampa rivers. The relative abundance of alluvial deposits varies from less than 10 to more than 80 percent of the visible channel boundary between the Lodore Ranger Station and the downstream end of the study reach at River Mile 194. The regional structural geology and lithology at river level may be significant in determining variations in canyon-floor width and gradient which influence the relative abundance of alluvial deposits in the Green River.

Sediment data from five sites in the Yampa River Basin and the Upper Green River Basin have been collected by the USGS during an ongoing, multiyear study that began in 1998. These data were augmented with sediment data gathered at these sites in earlier years as part of other USGS studies and routine data collection activities. The sampling sites are:

(1) Yampa River above Little Snake River, near Maybell, Colorado, 09251100;
(2) Little Snake River, near Lily, Colorado, 09260000;
(3) Yampa River at Deerlodge Park, 09260050;
(4) Green River above Gates of Lodore, Colorado, 404417108524900 (nearest streamflow gage, Green River near Greendale, Utah, 09234500); and
(5) Green River near Jensen, Utah, 09261000.

The period of record, number of samples, and type of sediment analyses vary at each of the sites. The sites with the shortest periods of record are the Yampa River above Little Snake River (1998-2000) and the Green River above Gates of Lodore (1999-2000); both sites data include suspended and bedload measurements. Suspended-sediment measurements were made at the Little Snake River, near Lily site in 1994-98 and in 2000; however, no bedload measurements were made. Suspended- and bedload-sediment measurements were made at the Yampa River at Deerlodge Park site in 1982-83 and 1998-2000, and only suspended-sediment measurements were made in 1994 and 1997. Suspended-sediment measurements were made at the Green River near Jensen site from 1948-79. These data were analyzed by Andrews (1986) but are not included in this report. Suspended- and bedload-sediment measurements were made at the Green River near Jensen site from 1996-2000. Sediment load by particle-size range and by hydrograph season also were computed for part of the record at all sites.

One objective of this study was to identify future data needs for improving the accuracy of sediment-transport relations that can be used in calculating sediment budgets at the five sampling sites. Sediment-transport curves were derived by least-squares regression of logarithmic-transformed data to provide a means to estimate seasonal and annual sediment supply to the principal streams in the upper part of the watershed (the Yampa River, the Little

Snake River, and the Green River upstream from the Gates of Lodore) and on the Green River just upstream from a critical spawning habitat near Jensen, Utah. These transport curves can be revised as additional data from the ongoing sampling program become available.

The relative accuracy and representativeness of the transport relations derived in this study were assessed using the coefficients of determination (R^2) of regression equations, the range of discharges sampled, the seasonality of the relations, and the number of samples. The transport equations in this report are considered to be reasonably representative if the R^2 is greater than about 0.70, if sediment samples are evenly distributed over the likely range of streamflow discharges in a year, if the samples are distributed between the rising-limb and falling-limb hydrograph seasons, and if the number of samples is large enough to reflect the variance in the relation between sediment-load and water-discharge.

The sediment-transport equations presented in this report indicate that gravel, sand, silt, and clay transport in these rivers is strongly dependent on the streamflow magnitude and, to a lesser degree, on the season. The timing of annual runoff and consequently the timing of sediment entrainment, transport, and deposition affect aquatic habitat and are dependent on long-term climate and seasonal weather patterns and on the operation of upstream reservoirs. Reach-specific estimates of the timing, volume, and particle size of sediment deposited at critical aquatic-habitat sites other than at the gaged sampling sites require streamflow routing through the drainage network and are beyond the scope of this report.

Yampa River above Little Snake River, near Maybell, Colorado

The relatively large R^2 values for all transport equations at station 09251100 suggest that the transport equations may be useful for annual load estimation or sediment budget calculations over discharges ranging from about 500- to 10,000-ft^3/s; however, the small number of samples may not reflect the population variance. Many of the sediment measurements were clustered in the discharge range from about 4,000- to10,000-ft^3/s. Consequently, these transport equations may not adequately reflect transport conditions of moderate-level discharges (for example, in the 600- to 4,000-ft^3/s range) or of higher discharges as occurred in 1997 or in the mid 1980s before the streamflow gaging station was established. Additional measurements in the 600- to 4,000-ft^3/s range from both the rising-limb and falling-limb hydrograph seasons and above about 10,000-ft^3/s would make these equations more representative of flow conditions at this site.

Little Snake River near Lily, Colorado

The sediment measurements at station 09260000 are relatively evenly distributed over streamflows from about 50- to 6,000-ft^3/s; however, sediment measurements at streamflows approaching the 1984 historical instantaneous peak discharge (16,700-ft^3/s) have not been made. The transport equation for suspended-sediment load is adequate for estimating annual suspended loads over discharges ranging from about 50- to 6,000-ft^3/s and may have some applicability over discharges ranging from about 1- to 50-ft^3/s. The suspended-sediment load transport equation must be recomputed with data from discharges greater than 6,000-ft^3/s for it to be applicable at extremely high discharges. Transport equations by particle size are applicable over discharges ranging from about 50- to 6,000-ft^3/s. Although the distribution of data suggest a seasonal sediment-load hysteresis may exist, the relatively low R^2 values for the hydrograph seasons could be improved with additional data collected in the appropriate seasons. Also, since bedload data have not been collected at this site, neither the total-annual sediment load nor the relative portion of total-sediment load transported as bedload are known. Bedload might be an important component of the annual sediment budget that should be quantified with future measurements.

Yampa River at Deerlodge Park

Suspended- and bedload-sediment data were collected at the Yampa River at Deerlodge Park site near the 1983 instantaneous peak discharge of 23,400-ft^3/s, but no sediment measurements were made the following year during the historical instantaneous peak discharge (33,200-ft^3/s). The recent effort to collect sediment data at Deerlodge Park has increased the number of suspended-sediment measurements by 124 percent and has increased the number of total sediment (suspended-sediment plus bedload-sediment) measurements by 58 percent since the 1980's. Based only on the relative magnitudes of the R^2 value, the additional data have resulted in a slightly improved suspended-sediment transport equation (0.82 compared to 0.76) and a slightly deteriorated total load equation (0.75 compared to 0.79). The revised transport equation for suspended-sediment load may be useful for annual suspended-sediment load calculations over discharges ranging from about 40- to 18,000-ft^3/s, whereas, the revised transport equations for total sediment load, suspended-sediment load, sand and gravel load, and fine sand load may be useful for annual load calculations over discharges ranging from about 600- to18,000-ft^3/s.
Except for measurements made above, about 18,000-ft^3/s, additional data collection may not improve these transport equations. However, more bedload measurements made during streamflows of less than about 700-ft^3/s could improve the accuracy of both the bedload-transport and total-sediment transport equations. Additional data collection during the rising-limb and falling-limb hydrograph periods might improve the transport equations that describe seasonality.

Green River above Gates of Lodore, Colorado

Sediment-transport equations for total-sediment load, suspended-sediment load, silt and clay load, and sand and gravel load had R^2 values greater than 0.78. The equation for bedload had an R^2 value of only 0.42, possibly due to a relatively limited range in bedload magnitude typical of river reaches with a limited supply of transportable bed material, such as rivers downstream of dams. The seasonal transport equations had R^2 values of 0.84 or greater but were based on small samples and, therefore, may not accurately reflect true seasonal conditions. Many of the sediment measurements were clustered in the streamflow range between about 4,500- and 10,000-ft^3/s, stream flows that occur relatively infrequently. Consequently, although most R^2 values are high, the equations do not adequately reflect moderate-level discharges (for example, in the 1,000- to 5,000-ft^3/s range), or of discharges approaching the postregulation instantaneous peak discharge of 13,700-ft^3/s. Additional sediment measurements made in the 1,000- and 5,000-ft^3/s range in both early and late hydrograph seasons or made near the postregulation instantaneous peak discharge could improve the accuracy of the transport equations. Additional measurements also might result in a better understanding of the variation in dominant transport mode (bedload compared to suspended load) over a wide range of streamflows.

Green River near Jensen, Utah

Sediment-transport equations for total-sediment, suspended-sediment, and transport by all particle sizes except very coarse sand and gravel had R^2 values of 0.70 or greater and may be useful for annual load estimations or sediment budget calculations over a discharge range from about 2,000- to 22,000-ft^3/s. The equation for bedload transport had an R^2 value of 0.46, and the equation for very coarse sand and gravel had an R^2 value of 0.54. Rising-limb and falling-limb season equations had R^2 values of 0.81 and 0.75, respectively, but these equations were based on relatively small samples and could be improved with more data. Most of the sediment data were collected at stream flows between about 5,500- and 22,000-ft^3/s, and only three measurements were made at stream flows between 1,770- and 3,360-ft^3/s. Also, no sediment measurements have been made at stream flows approaching the 1984 historical instantaneous peak discharge of
40,000- ft^3/s.

The representativeness of all transport equations at this site could be improved with additional sediment measurements in the range of about 2,000- to 5,500-ft^3/s and at discharges greater than 22,000-ft^3/s. The suspended-sediment transport equation derived from the 30 measurements made since 1996 has a significantly different slope and intercept than the postregulation period equation derived by Andrews (1986) and, based on the R^2 value, a lesser variance. Resolution of these differences is another justification for making additional sediment measurements at the Jensen site.

VII. Recommendations:

Recommendations were presented under each sediment site presented above.

VIII. Project Status: 2002 was the last year of data collection on the Yampa/Green rivers, the program has directed future work to the Gunnison River.

IX. FY 2002 Budget Status:

A. Funds Provided: $45,000
B. Funds Expended: $45,000
C. Difference: $ 0

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The USGS has provided $25,000 of match for this project to do additional analysis and correlation with data collected earlier in the century.

X. Status of Data Submission:

A review draft report is available and was sent to the Geomorphology Peer Review panel and 10 other knowledgeable Recovery Program participants for comments. To date the comments have been constructive and positive. The review process will be competed in mid- February 2003 and a final USGS Water-Resource investigation should be completed by June 2003.

XI. Signed: *George Smith*, for John Elliot — December 19, 2002
Principal Investigator — Date

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